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A NEW METHOD OF MEASURING SHORT
HALF-LIVES.

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THE EFFECT OF FLOWERS AND INSECTIVORES

Abstract of

A Thesis

Presented in Partial Fulfillment of the Requirements for
the Degree Master of Science

By

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The Ohio State University

1950

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A REVIEW OF MEASURING SHORT HALF-LIVES

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B.S., United States Military Academy, 1946

Department of Physics
(Approved by James C. Harris)

A review of several methods of measuring the half-lives of short-lived radioisotopes is presented. Then a new method is described which utilizes a cathodoluminescent oscilloscope in conjunction with three phototubes and associated electrical circuits. The design and construction of the concomitant apparatus is taken up in detail. The method described is then applied to the specific problem of measuring the half-lives of the isotopes aluminum twenty-five and aluminum twenty-six, which result from the bombardment of magnesium twenty-four and magnesium twenty-five respectively with protons accelerated by a Van de Graaff generator. The values obtained for the half-lives are reported as follows: aluminum twenty-five -- seven and eleven hundredths seconds plus or minus thirteen hundredths of a second; aluminum twenty-six -- seven and sixty-nine hundredths seconds plus or minus twenty-one hundredths of a second. In conclusion the capabilities and limitations of the new method described are delineated, and future applications are suggested.

A PROGRAM OF CONTINUING adult EDUCATION

A Thesis

Presented in Partial Fulfillment of the Requirements for
the Degree Master of Science

By

ROBERT S. VESTER DARTH, B.S.

The Ohio State University

1952

Approved by:

Adviser

ANSWERING YOUR QUESTIONS BY LETTER AND
E-MAIL

AND COMMUNICATING WITH THE ASSOCIATION THROUGH THE
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Historical Review and Introduction

Before proceeding to a description of a new method of measuring the half-lives of short-lived radioisotopes it is perhaps advisable to describe some of the methods which have been used successfully in the past. In this regard *U. M. Plant*⁽¹⁾ has given an excellent review of several methods, some of which will now be discussed.

Attempts to measure the half-life of Ra C' (1.55×10^{-4} sec.) gave rise to three different methods of measuring short half-lives, all of which depend on the radioactive daughter isotope of interest being formed from a radioactive parent whose half-life is long compared to that of the daughter. These methods may be called (1) the pulse-lengthening method, (2) the delayed pulse method, and (3) the oscilloscope method.

The pulse-lengthening method has been developed by Danforth⁽²⁾ and Rotblat^{(3), (4)}. It utilizes two counters, one of which is sensitive to the beta radiation from Ra C and one of which is sensitive to the alpha radiation from Ra C'. The pulses from the two counters are amplified separately, made of uniform size, and then fed into a coincidence circuit. The length of the beta pulses is varied and the number of coincidences per unit time observed as a function of the length of the pulses. That the graph of the coincidences per unit time versus the length of the pulse is the inverse of

the Ra C' decay curve may be seen from the considerations below.

The general law of radioactive decay may be written as

$$N = N_0 e^{-\lambda t} \quad (1)$$

where N = the number of atoms of a radioactive material remaining at the end of a time t ; N_0 = the initial number of atoms; and λ = the decay constant.

If N_0 be put equal to one and the differential of (1) taken, the result is

$$dN = -\lambda e^{-\lambda t} dt \quad (2)$$

From (2) it may be seen that the probability for a given atom to live a time t and then decay in the interval from t to $t+dt$ is $\lambda e^{-\lambda t} dt$. Thus the probability for the emission of an alpha particle during the time τ , or what is the same thing, the rate of coincidence when the beta pulse has a length τ is

$$C = N_0 \int_0^\tau \lambda e^{-\lambda t} dt \quad (3)$$

where λ is the decay constant of Ra C' and N_0 is the initial number of Ra C' atoms.

Evaluating the integral in (3) leads to

$$C = C_{\max} (1 - e^{-\lambda \tau}) \quad (4)$$

where C_{\max} is the maximum coincidence rate, which will be attained when τ becomes infinite. For infinite τ , $C = C_{\max} = N_0$. From (4) it can be seen that the coincidence rate increases exponentially with the beta-pulse length in a manner

Using the *getFoliation* method the following code is an example of how to get the foliation for a point in each of the three sub-manifolds:

• (5)

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For Σ it is mainly γ with contributions from α_1 and α_2 with $\alpha_1 = \alpha_2 = 0.2$, γ is about 0.5, α_3 and α_4 are negligible and α_5 and α_6 are 0.1. For Δ it is mainly γ with contributions from α_1 and α_2 with $\alpha_1 = \alpha_2 = 0.2$, γ is about 0.5, α_3 and α_4 are negligible and α_5 and α_6 are 0.1.

determined by the decay constant λ . Hence it is possible to compute the half-life of Ra C' from the experimental relationship observed between the coincidence rate and the length of the beta pulse.

The delayed pulse method has been developed by Jacobsen and Sigurgeirsson (5). As in the previous method two counters are used, one sensitive only to beta radiation and the other sensitive only to alpha radiation. The outputs of the two counters are fed into a coincidence circuit as before. Now, however, instead of lengthening the beta pulse the arrival of the beta pulse is delayed a variable length of time. As before the probability that an atom decays in the interval between t and $t+dt$ is $\lambda e^{-\lambda t} dt$. When the pulse widths are short compared to the half-life being measured this is equivalent to the probability that a coincidence be recorded after the beta pulse has been delayed t units of time. Therefore the coincidence rate may now be expressed as

$$C = N_0 \int_{\tau}^{\tau + \tau_c} \lambda e^{-\lambda t} dt \quad (5)$$

where τ is the delay time of the beta pulse; τ_c is the maximum length of time by which two pulses may be separated and still be recorded as a coincidence; λ is the decay constant of Ra C'; and N_0 is the initial number of Ra C' atoms. Integration of (5) gives

$$C = N_0 e^{-\lambda \tau} (1 - e^{-\lambda \tau_c}) \quad (6)$$

If one now denotes by C_0 the value of C when $\tau = 0$, it is

easily seen that

$$N_0 = C_0 / (1 - e^{-\lambda \tau} C) \quad (7)$$

with this substitution (6) becomes

$$C = C_0 e^{-\lambda \tau} \quad (8)$$

From (8) it is clear that a graph of the observed rate of coincidence versus the delay time of the beta pulses will give a decay curve for $^{40}\text{Ca C}'$ from which the half-life may be easily computed.

The oscilloscope method has been developed by Newlands. (6), (7) Two counters are used as in the previous two methods. This method does not, however, utilize a coincidence circuit. Instead, the beta pulse is used to trigger a single sweep on a cathode ray oscilloscope and the alpha pulse is applied to the vertical deflection plates. By this means it is possible to observe directly the time intervals between pulses simply by noting the position of the alpha pulse on the oscilloscope screen. The number of alpha pulses observed after a time delay τ will be

$$N = N_0 \int_{\tau}^{\tau + 4\tau} \lambda e^{-\lambda t} dt \quad (9)$$

where 4τ is the smallest unit of time observable on the oscilloscope time scale being used; λ is the decay constant of $^{40}\text{Ca C}'$ and N_0 is the initial number of $^{40}\text{Ca C}'$ atoms. As in the delayed pulse method this may be readily integrated to give

$$P = N'_0 e^{-\lambda \tau} \quad (10)$$

where now N'_0 is the number of alpha pulses having a zero time

to determine the effect of the α parameter on the β parameter.

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34) $\beta = 0.5$ and $\alpha = 0.5$ (34) $\beta = 0.5$ and $\alpha = 0.5$

delay; by analogy to (7) E'_0 is equal to E_0 ($1-e^{-\lambda \Delta t}$), so it is evident that a plot of alpha pulses versus observed delay time will give a decay curve for α C' from which the half-life can be easily determined.

It appears on the surface as though none of the three methods just described could be utilized to measure the half-life of a radioactive isotope which is the only product nuclei of, say, a nuclear reaction and which decays to a stable isotope. Actually, however, De Bennett and McGowan⁽²⁶⁾ have shown that the delayed pulse method may be used to measure the half-life of a single isolated radioactive material. Several other methods also applicable to this case will now be discussed.

In a method originated by Socley and Fajans⁽⁸⁾ and developed by Becker and Gaertner⁽⁹⁾ a target is deposited on a disk which rotates at high speed. The target is then bombarded with nuclear projectiles from some sort of an accelerator, and the activity is measured as a function of the angular displacement from the point of bombardment. From this data the half-life of the activity may easily be computed.

Cassels and Latham⁽¹⁰⁾ have used a cyclotron modulated to give short bursts of particles. In between the bursts, the counter measuring the radioactivity of the target is connected in turn for equal time intervals to each of ten

separate recorders. The half-life of the activity may then be easily computed from the data obtained. Cassels and Iethan claim that this method is good for half-lives ranging from 100 microsec. to 1 sec. The fact which sets a lower limit to the half-life measurable by this technique is the recovery time of the counter being used to measure the activity. The use of scintillation counters, which have recovery times on the order of 10^{-3} sec., would increase the range of applicability of this method considerably.

For half-lives longer than a few seconds, a target may be bombarded and then removed to an adjacent counter of some sort which measures the activity and the decay of the induced radioactivity. The main difficulties in this procedure are getting the radioactive target from the place of bombardment to the counter before the activity has decayed too much, and devising a timing mechanism to accurately fix the time intervals during which the counter counts. The number of counts obtained must also be recorded in some fashion. The counting interval should, of course, be reasonably small compared to the half-life being measured. Different research workers^{(1),(11),(12)} have devised various methods to surmount the difficulties mentioned. For more specific information the literature may be consulted.

In general the methods for measuring short half-lives just described have limited ranges of applicability and require complicated electronic circuits which are not avail-

able commercially. The new method which will be described in this thesis has a range of applicability from approximately 1 milliseec. to 1 min. and utilizes for the most part commercially available equipment. The associated electrical circuits which must be constructed are simple in design and not difficult to assemble. Although the method was designed for use with a Van de Graaff generator, it could easily be adapted for use with any other type of accelerator. After the general theory and construction of the equipment have been discussed, descriptions of two experiments utilizing the method will be given. The results of these experiments will be discussed and finally future applications of the method will be suggested.

General Description of Method and Equipment

The method discussed below was devised for use with the Van de Graaff generator at Ohio State University. A general description of the pieces of equipment necessary and the tasks performed by each follows.

A shutter was constructed to interrupt the Van de Graaff generator beam. Simultaneously with interrupting the beam the shutter actuates a micro switch which in turn actuates a relay raising a lead shield from between the target being bombarded and an active Geiger tube. The pulses from the

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Geiger tube are fed into the vertical deflection plates of a cathode ray oscilloscope. The microswitch mentioned before also closes an electric circuit which triggers a single sweep of the electron beam across the face of the oscilloscope. Positioned at definite intervals along the time axis of the oscilloscope are three lucite tubes which pipe light to three separate type 931-A photomultiplier tubes. Each photomultiplier tube is followed by its own preamplifier and its own independent scaler. Thus during a single sweep of the electron beam across the face of the oscilloscope a certain number of pulses will be "seen" by each phototube and recorded on the appropriate scaler. This will give three points on a decay curve of the activity being counted. Of course, this routine must be gone through many times to obtain sufficient counts on each scaler to give a small probable error. The time base of the oscilloscope sweep must be adjusted to a value commensurate with the half-life of the activity being measured.

It is seen from the preceding description of the new method that the equipment necessary is:

- (1) A Van de Graaff generator.
- (2) A shutter for interrupting the Van de Graaff generator beam.
- (3) A Geiger tube.
- (4) A cathode ray oscilloscope.
- (5) Three phototubes with individual preampli-

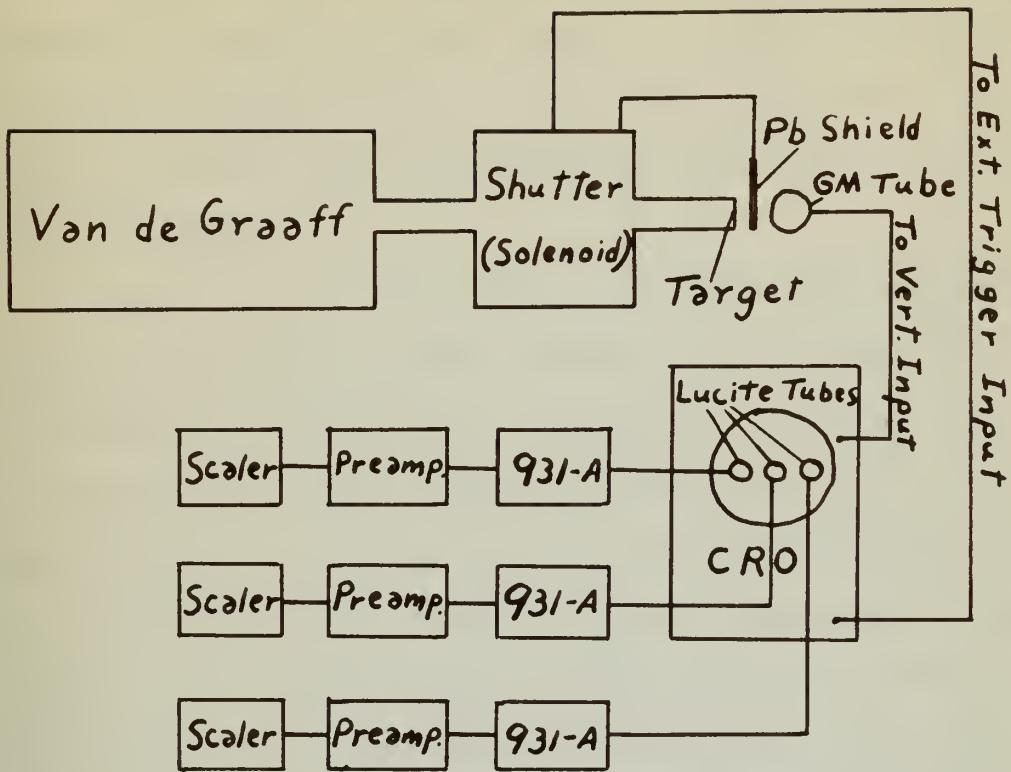
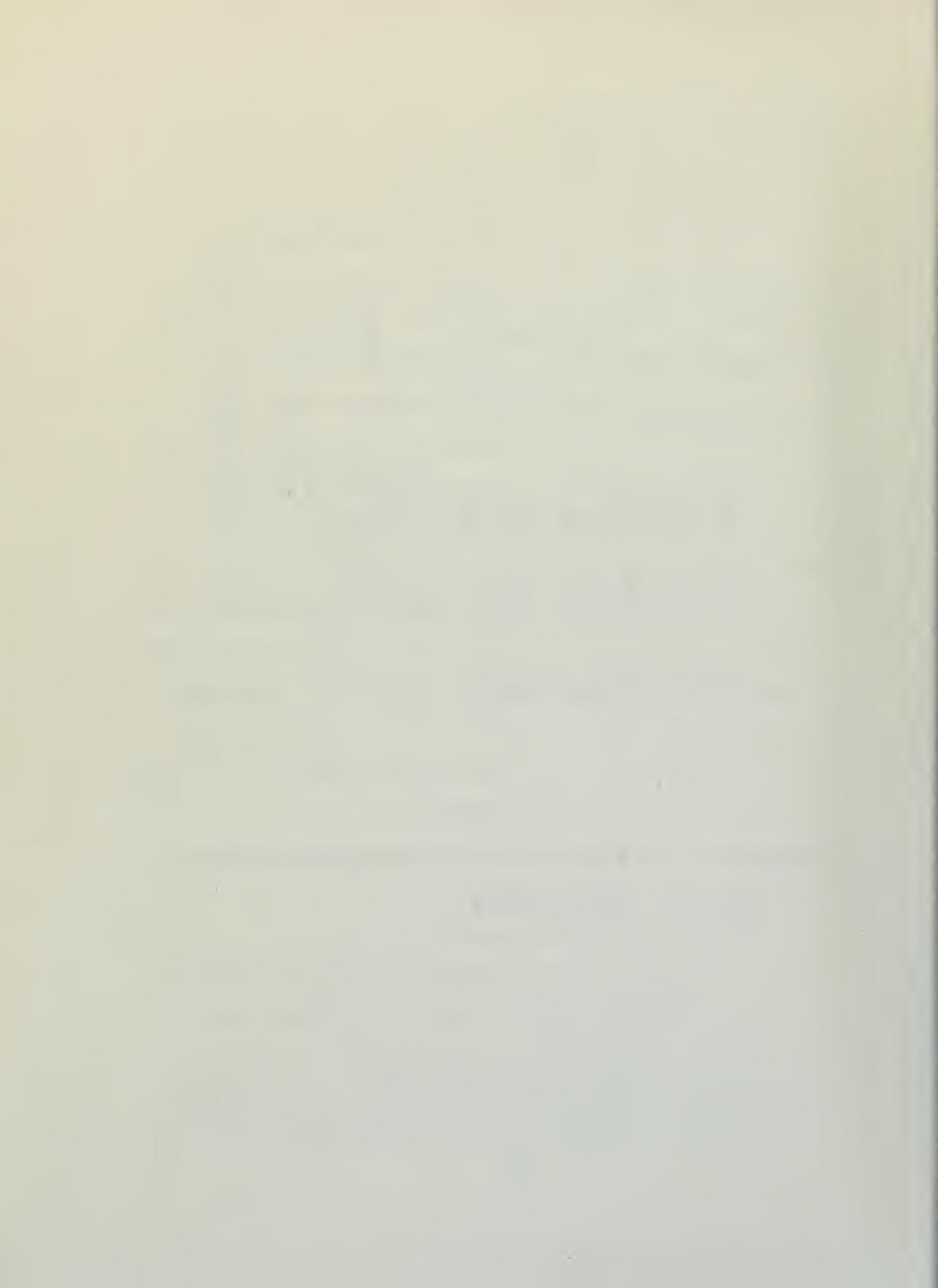


Figure 1. Sketch of arrangement of various equipment.



ifiers and independent outputs.

(6) Three scalers.

(7) Various voltage supplies.

Figure 1 is a sketch illustrating the proper relationship of this equipment. Items (2) and (5) in the above list require a special description since they had to be designed and constructed.

Figure 2 is a sketch of the shutter used in this work. As can be inferred from the sketch the motivating force for the shutter is provided by a solenoid. When this solenoid is actuated by a hand switch in series with a 200 volt D. C. power supply the soft iron core is drawn inside the solenoid, cutting off the Van de Graaff beam and actuating the micro-switch. The solenoid draws 70 milliamperes of current. When the hand switch is turned off a spring draws the shutter back so that the Van de Graaff beam is again bombarding the target.

Figure 3 is a circuit diagram of one phototube and its preamplifier. There are two more identical units. Several general references were consulted in the design of these circuits. (13), (14), (15), (16), (17)

Figure 4 is a photograph of all three units complete, showing the lucite tubes and the framework by which the whole is fastened to the face of the oscilloscope. The lucite tubes were first shaped and then cemented to the 931-A phototubes by means of Canada balsam. The phototubes were

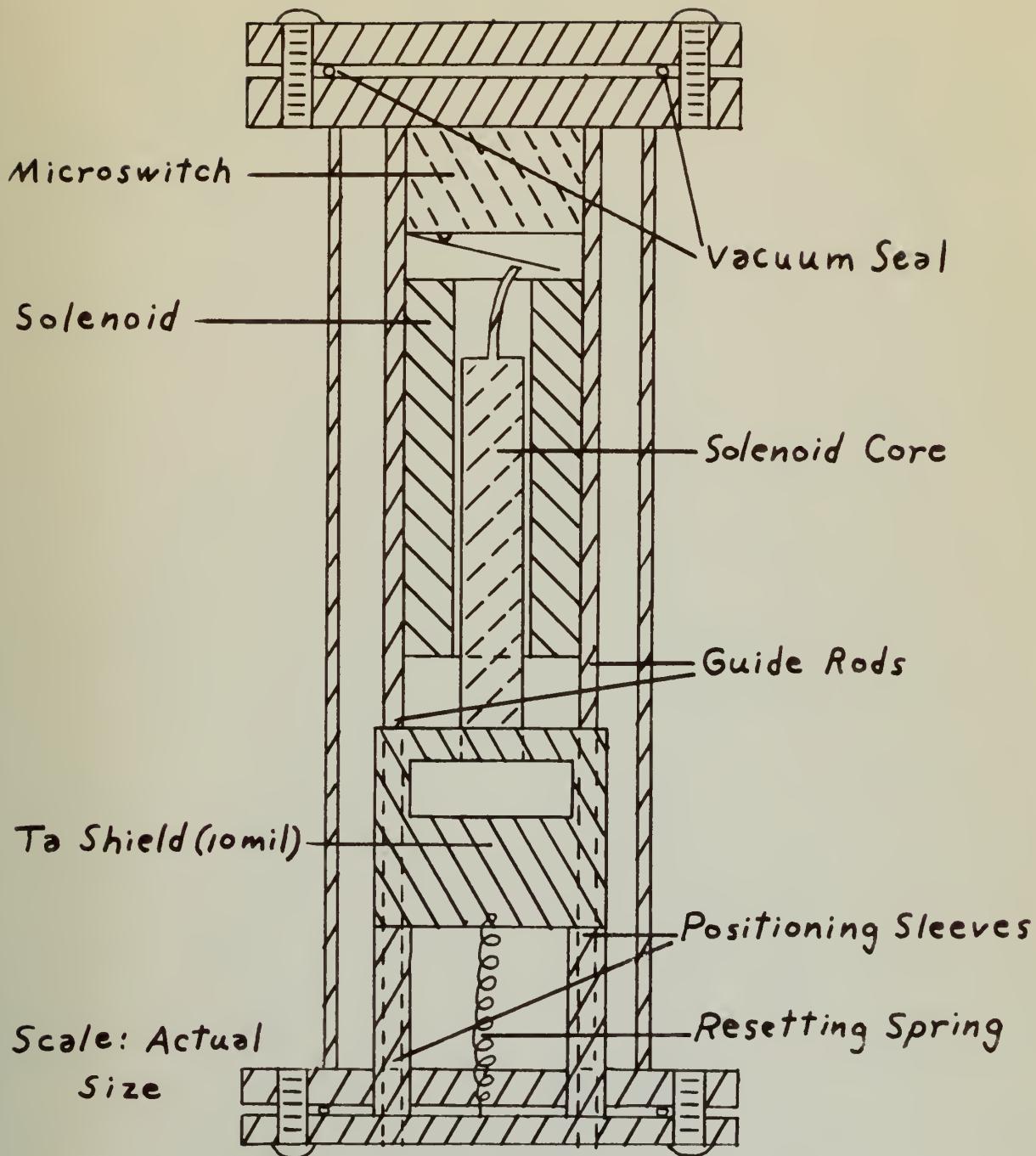


Figure 2. Cross-sectional sketch of shutter.

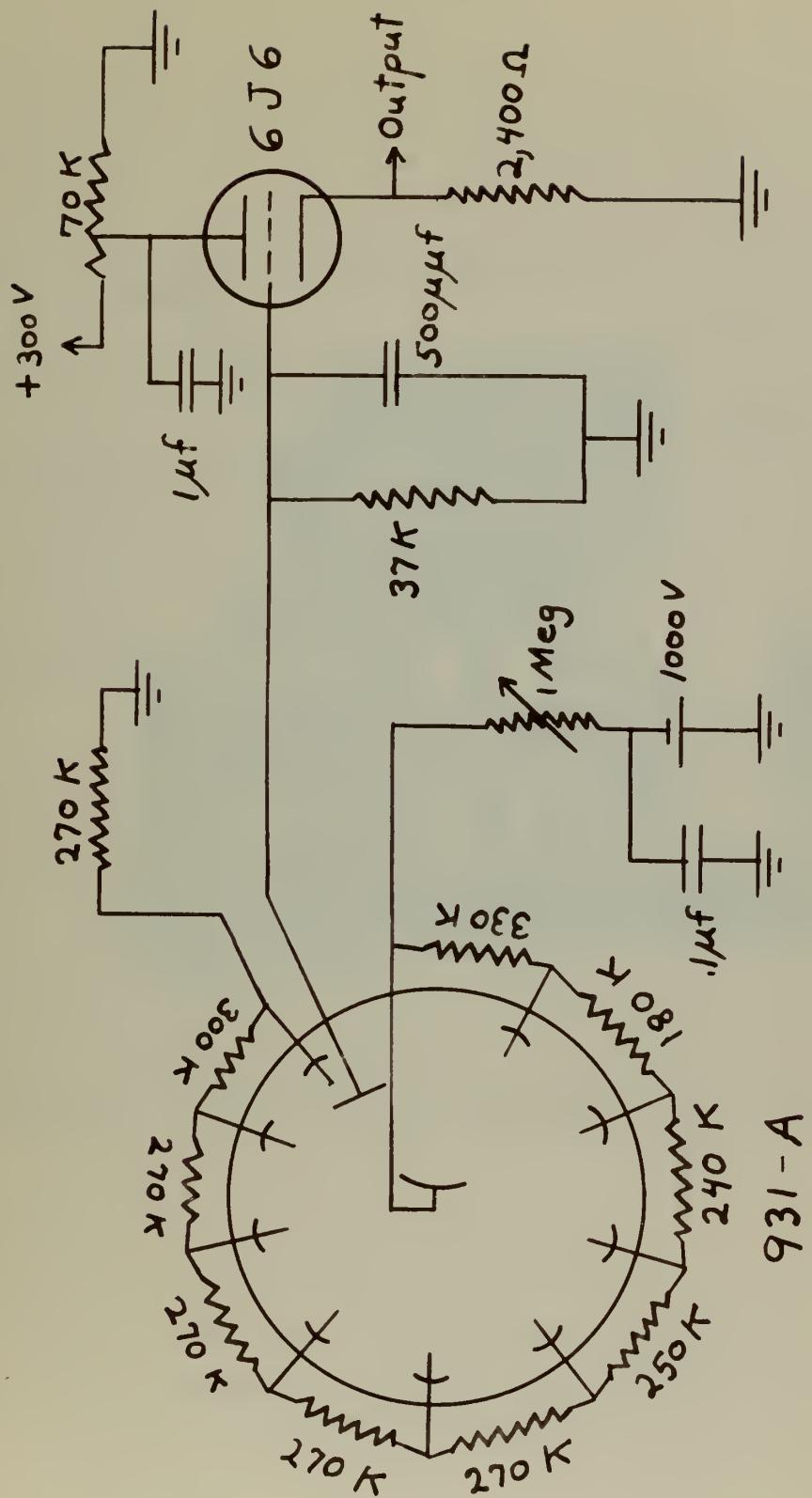
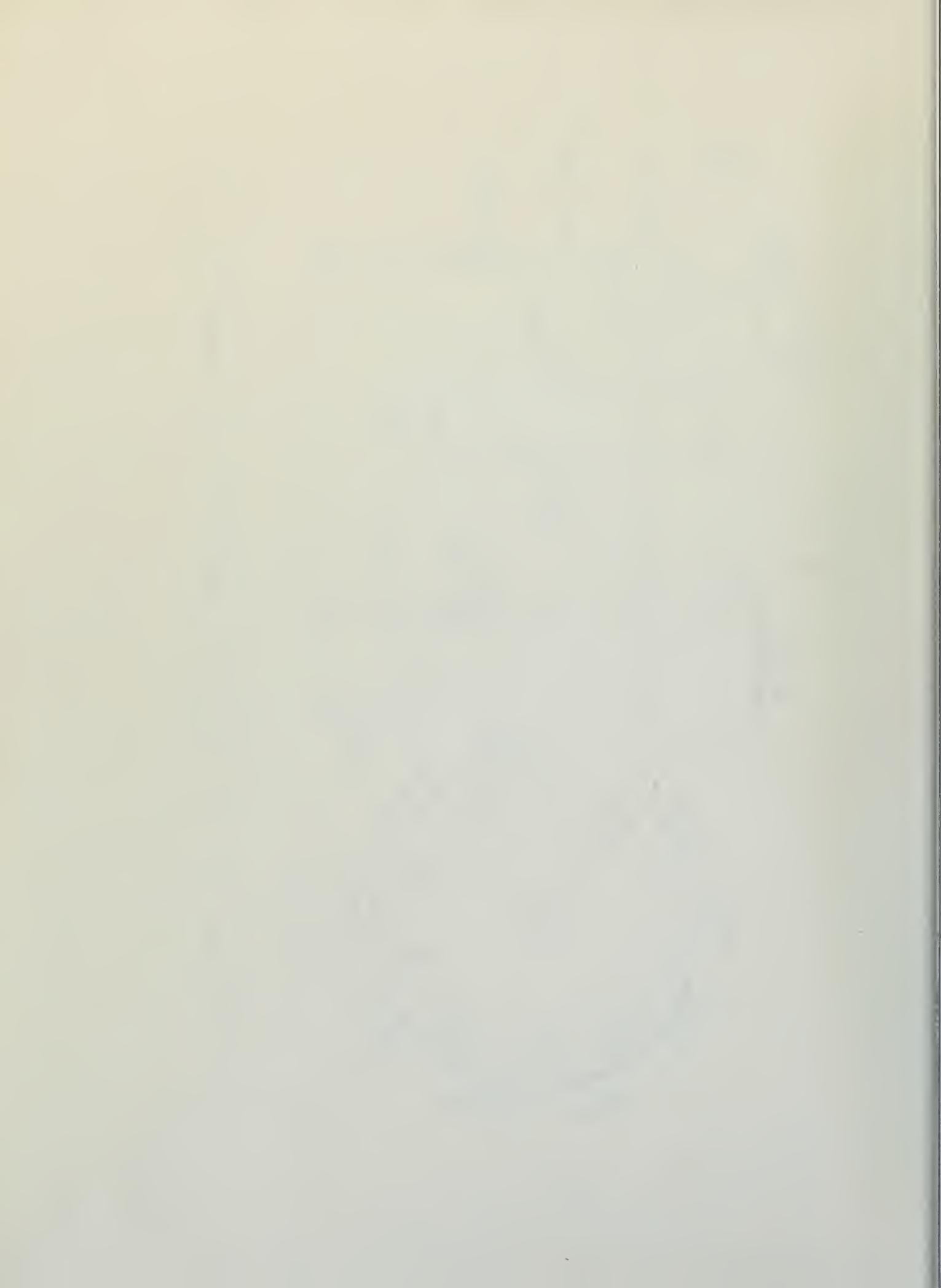


Figure 3. A typical phototube-preamplifier unit.



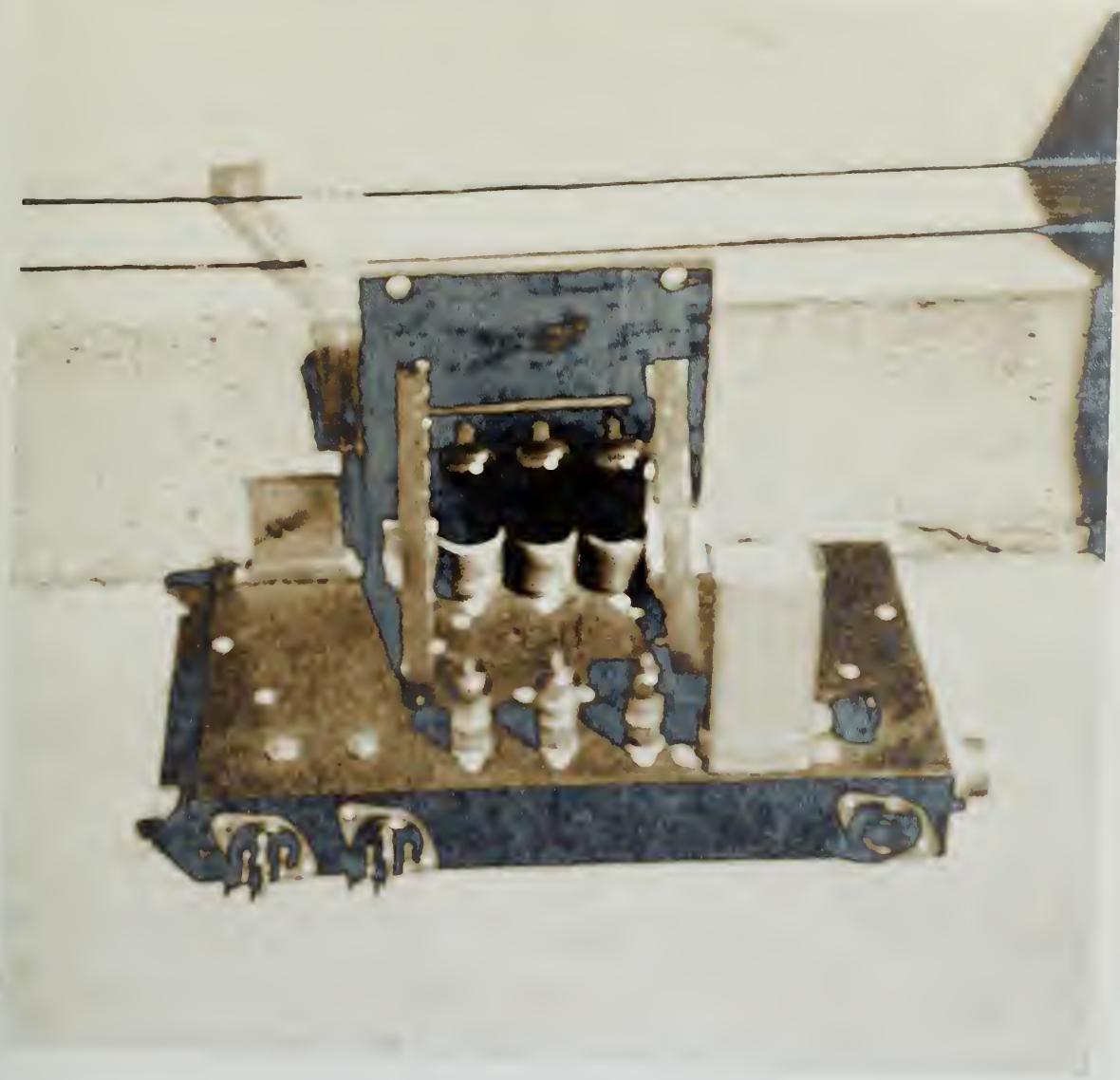


Figure 4. Photograph of complete phototube - preamplifier unit.



painted black to keep out undesired stray light. A pressure fit for the end of the lucite tubes against the face of the oscilloscope was found to be satisfactory. It should be noted that the variable resistances placed in the phototube circuits permit independent adjustment of the voltage across each phototube (within certain limits). This was found to be necessary since the 931- tubes used did not have precisely the same characteristics as a function of voltage. It is imperative that the same number of counts be registered by each phototube from the same source of light impulses. By adjusting the voltage properly on each phototube it was possible to attain this desired condition.

Specific Experiments Performed

After this equipment was designed and constructed, it was decided to apply it to the problem of determining the half-lives of the two radioisotopes Al^{25} and Al^{26} , both of which are in the neighborhood of 7 sec. Since there was no sweep time as large as 7 sec. available on the oscilloscope, it became evident that the general method already described would have to be modified slightly for this problem. An auxiliary sweep circuit of the desired length could have been built, but this was decided against in favor of a much simpler idea. Instead of triggering a sweep across

concerns in addition to those of the individual.
The only real concern would seem to be how well such an
alliance fit. An alliance can not benefit one organization with
only one primary communication addressed and their bodies and
only the communication addressed addressed exclusively.
A possible alliance situation may however prove to be more favorable
than others in that both organizations can benefit from the other.
The problem here will likely be alignment of the two
organizations and possibly how to harmonize the different
communication systems and protocols of the different organizations.
Such a situation will involve a certain amount of planning and a certain amount
of time.

Business communication systems

As previously mentioned, two organizations have a certain
number of communication links and for the time the following
are the best. The best communication system will be specialized
in one specific system. This is the Encapsulated System with the
communication links to the individual system. The system will have
several different protocols. These are the best because most of
the protocols used will have the maximum amount of data
against the lowest amount. This is true with the Encapsulated system.
A lot of data at the lowest amount can have the lowest cost and
minimum latency. A disadvantage to this system is that the data will

the face of the oscilloscope the electron beam was left focussed on a spot directly under one of the lucite tubes connected to one of the phototubes. The other two phototubes were disconnected completely. Periodically a voltage was applied to the horizontal deflection plates of the oscilloscope to move the spot out from under the lucite tube of the active phototube. This method had the definite advantage that all of the pulses from the Geiger tube were counted while the electron beam spot was focused under the lucite tube.

The periodic application of a deflecting voltage to the horizontal deflection plates of the oscilloscope was accomplished as follows. A scaler was set to a scale of 64 and then allowed to count the 60 cycle A. C. line frequency. The resulting pulse every $64/60$ of a second was fed into an external register. The external register had a sliding metal contact which made contact with the rotating wheel of the mechanical register. However, at definite intervals around the wheel scotch tape was placed so that the electrical contact was broken periodically. In particular the scotch tape was arranged so that the electrical contact was made for $2(64/60)$ seconds then broken for $3(64/60)$ seconds. For convenience hereafter $(64/60)$ sec. will be spoken of as one time unit. With a $22\frac{1}{2}$ volt battery in series with the electrical contact and the horizontal deflection plates of the oscilloscope, the photo-

tube counted for 2 time units, did not count for 3 time units, counted for 2 time units, etc.

Another difficulty arose when it was found that the pulses coming from the preamplifier following the phototube was not large enough to trigger a Tracerlab auto-scaler. It had triggered the Atomic Instrument Co. Model 1030 scaler very nicely, but this scaler was not available for the purpose of counting the phototube pulses. Consequently a two-stage amplifier was designed and constructed to amplify the preamplifier pulse enough so that the auto-scaler would record it. The circuit diagram of this amplifier is given in Figure 5.

Utilising the modifications mentioned above, the following experiment was performed. A target of isotopically pure Tg^{24} was bombarded with protons of energy 224 kev. This energy is at a resonance peak for $Tg^{24}(p,\gamma)Al^{25}$. After bombarding for thirty sec. a switch was thrown actuating the solenoid which pulled the shutter up, interrupting the Van de Graaff beam and closing the microswitch. The microswitch's closing actuated a relay which lifted a lead shield from between the target and an active Geiger tube. The Geiger tube then sent pulses to the vertical plates of the

*Obtained from Carbide and Carbon Chemicals Division, Y-12 Arden, Oak Ridge National Laboratory, upon allocation from the Atomic Energy Commission.

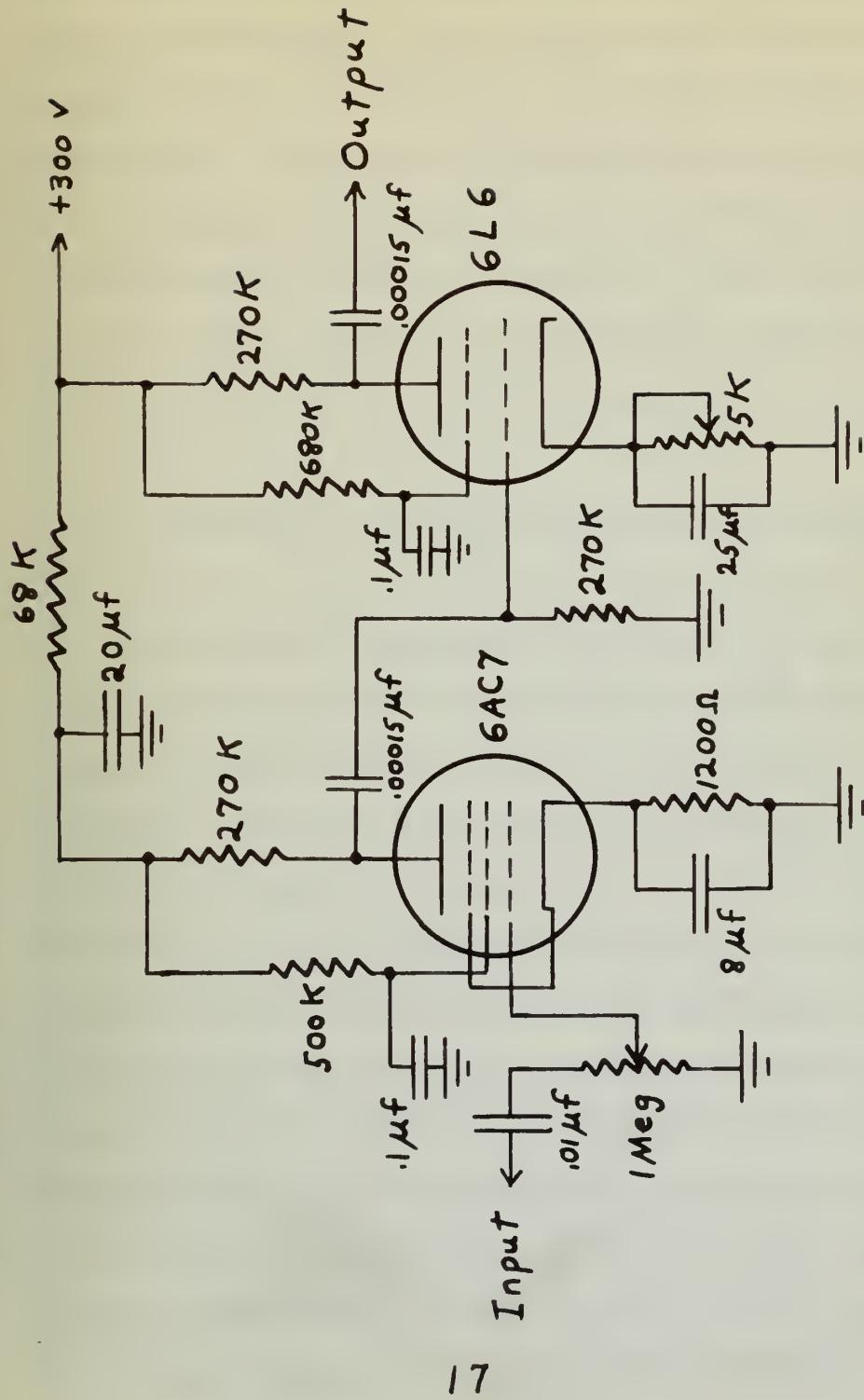
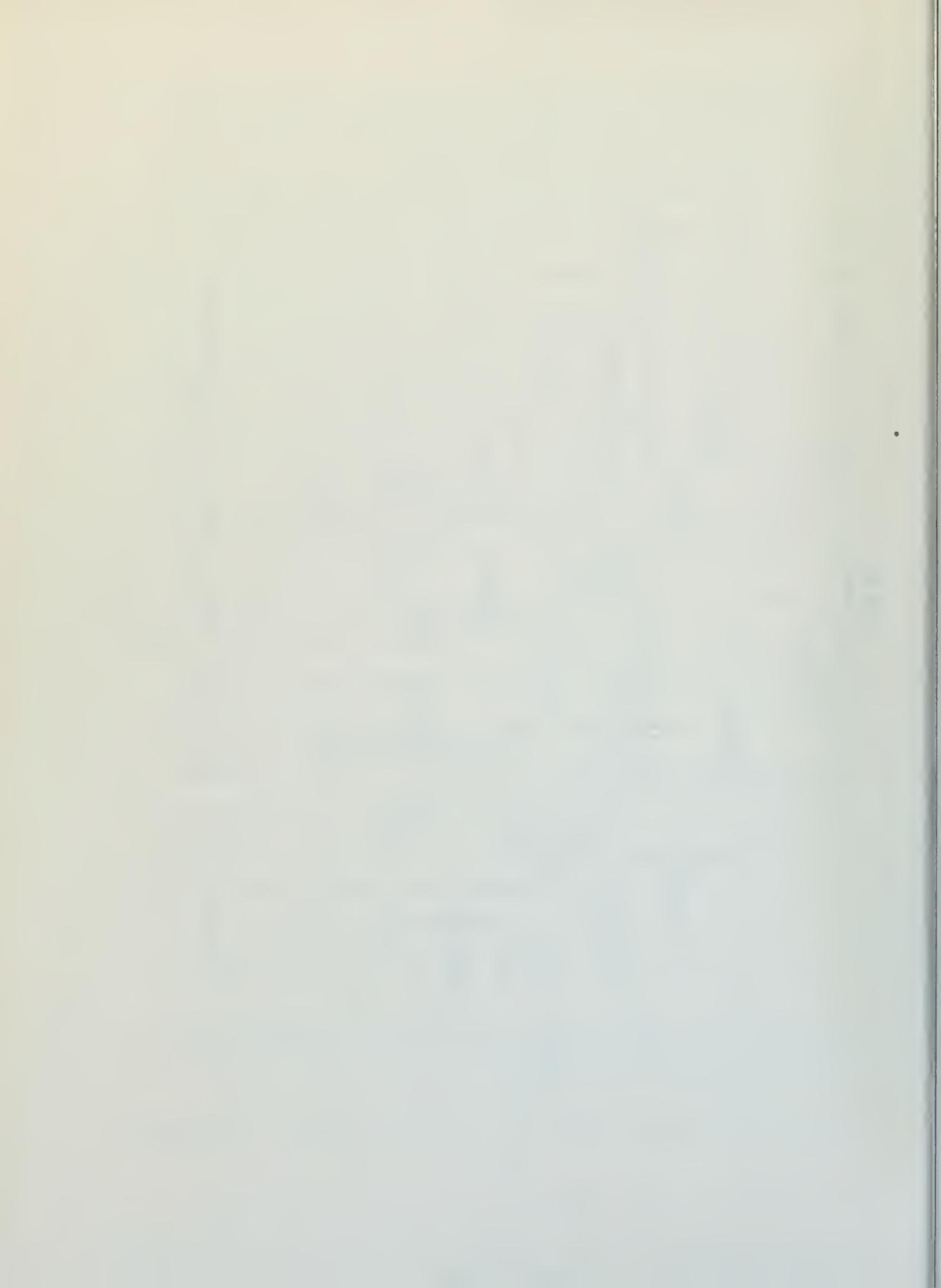


Figure 5. Circuit diagram of amplifier.



oscilloscope and the ph totube counted these pulses for 2 time-unit intervals. During the three time-units delay the number of pulses registered in the preceding two time units was recorded. This sequence of events was repeated many times to get sufficient counts to insure a low probable error. The data so obtained are given in Appendix I.

A similar experiment was then performed with a target of Ig^{25} , using protons of energy 565 kev. This energy is at a resonance peak for $\text{Ig}^{25}(\text{p},\gamma)\text{Al}^{26}$. The data obtained in this experiment are given in Appendix II.

Analysis of Data and Discussion of Results

In the first experiment described the nuclear reaction occurring is known⁽²⁹⁾ to be $\text{Ig}^{24}(\text{p},\gamma)\text{Al}^{25}$ so the radio-isotope whose activity would be measured is Al^{25} . All of the data obtained for the first time interval (2 time units) were added together as were those for all the other time intervals. This gave ultimately five points on the decay curve of Al^{25} . Figure 6 is a plot on semi-log graph paper of the results obtained from the data listed in Appendix I. The variations plotted are one standard deviation in length. The background counting rate was measured approximately in the middle of each experiment. While taking background data the shutter was closed, with the Van de Graaff beam bombarding it, and the lead shield was raised. Before

starting to record the background counts, the induced activity of the target was allowed to decay for one minute.

The value of a standard deviation was obtained in the following manner. Suppose the total number of counts for a given time interval to be N . If there were no background counts, the standard deviation, σ , would be \sqrt{N} . The fact that there are background counts must be considered, however. Suppose that the number of background counts in a given time interval is B . Then the standard deviation will be

$$\sigma = \sqrt{N + B} \quad (11).$$

To actually determine the half-life of Al^{25} from the data in Appendix I a line was fitted to the data using the method of least squares. A short derivation of the theory of this method is given. (16)

Suppose a set of N points, of which only the y coordinate is susceptible to error, when plotted on graph paper suggest a linear relationship with equation

$$y = mx + k \quad (12).$$

Now, let d_i be the difference between the ordinate of the i th point and the corresponding ordinate of the line. Denote the weight of y_i by w_i . The method of least squares assumes that the best fit will be obtained when the sum of the $w_i(d_i)^2$ is a minimum. This may be expressed as follows:

$$\sum w_i d_i^2 = \sum w_i [y_i - (m x_i + k)]^2 \quad (12)$$

is to be minimized.

(14) $[x - y^2] \geq 0$ $\forall x, y \in \mathbb{R}$

Expansion of (13) leads to

$$\begin{aligned}\sum w_i d_i^2 &= \sum w_i (y_i^2 + m^2 x_i^2 + k^2 - 2m y_i x_i - 2k y_i \\ &+ 2k m x_i)\end{aligned}\quad (14).$$

This may be further simplified to

$$\begin{aligned}\sum w_i d_i^2 &= k^2 \sum w_i + 2mk \sum w_i x_i + m^2 \sum w_i x_i^2 - 2k \sum w_i y_i \\ &- 2m \sum w_i x_i y_i + \sum w_i y_i^2\end{aligned}\quad (15).$$

Consider this now as a function of the two variables m and k . Say $\sum w_i d_i^2 = f(m, k)$. To determine the minima of $f(m, k)$ as functions of m and k respectively one needs only to take the partial derivatives of $f(m, k)$ first with respect to m and then with respect to k and in each case to set the result equal to zero. This gives the following two equations in the two unknowns m and k :

$$\frac{\partial f(m, k)}{\partial m} = 2k \sum w_i x_i + 2m \sum w_i x_i^2 - 2 \sum w_i x_i y_i = 0 \quad (16).$$

$$\frac{\partial f(m, k)}{\partial k} = 2k \sum w_i + 2m \sum w_i x_i - 2 \sum w_i y_i = 0$$

The solution to these equations may be written down immediately by Cramer's rule and is

$$k = \frac{\begin{vmatrix} \sum w_i x_i y_i & \sum w_i x_i^2 \\ \sum w_i y_i & \sum w_i x_i \end{vmatrix}}{D}; \quad m = \frac{\begin{vmatrix} \sum w_i x_i & \sum w_i x_i y_i \\ \sum w_i & \sum w_i y_i \end{vmatrix}}{D} \quad (17)$$

where $D = \begin{vmatrix} \sum w_i x_i & \sum w_i x_i^2 \\ \sum w_i & \sum w_i x_i \end{vmatrix}$

$$(18).$$

1. $\text{H}_2\text{O} + \text{H}_2\text{O} \rightarrow \text{H}_2 + \text{H}_2\text{O}$ (1)

2. $\text{H}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2 + \text{H}_2\text{O}$ (2)

3. $\text{H}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2 + \text{H}_2\text{O}$ (3)

4. $\text{H}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2 + \text{H}_2\text{O}$ (4)

5. $\text{H}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2 + \text{H}_2\text{O}$ (5)

6. $\text{H}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2 + \text{H}_2\text{O}$ (6)

7. $\text{H}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2 + \text{H}_2\text{O}$ (7)

8. $\text{H}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2 + \text{H}_2\text{O}$ (8)

9. $\text{H}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2 + \text{H}_2\text{O}$ (9)

10. $\text{H}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2 + \text{H}_2\text{O}$ (10)

H_2	H_2
H_2	H_2

11. $\text{H}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2 + \text{H}_2\text{O}$ (11)

H_2	H_2
H_2	H_2

This gives the solution in general.

Now in this case the several solutions of the radioactive decay being observed is

$$y = b e^{-\lambda t} \quad (15)$$

where t is the time coordinate, y is the reading rate, and b is equal to $-\lambda t_0$. To identify this situation with the equation this theory just developed one need only take the logarithm of both sides of (12) to get

$$\log_{10} y = \log_{10} k + (m \log_{10} e) x \quad (20).$$

If one puts $y' = \log_{10} y$, $m' = m \log_{10} e$, and $k' = \log_{10} k$, equation (20) becomes

$$y' = m' x + k' \quad (21)$$

which is obviously the form already treated.

It has been shown (32) that the proper weighting factor, w_1' , to use for the y_1' is $(2.303)^2 y_1'$. With y_1' substituted for y_1 and w_1' substituted for w_1 , equation (17) may be used to compute the constants m' and k' in equation (21).

The total number of counts, y_1 , obtained in the i th time interval was plotted at the center of the interval. Thus it was the center of each time interval which was denoted as x_1 . To be more precise one should use for x_1 the quantity \bar{x}_1 given by

$$\bar{x}_1 = \int_{x_0}^{x_f} e^{-\lambda x} dx / \int_{x_0}^{x_f} e^{-\lambda x} dx \quad (22)$$

where the limits of integration are from the initial conditions to the final conditions of the i th interval,

the α and β curves are symmetric with respect to the vertical axis.

and λ is the decay constant of the radioactive material being measured. Note that an assumed value for λ is necessary to evaluate equation (2). Moreover the fitted value of λ depends on x_1 ; hence a method of successive approximations must be used.

The more precise method of determining the x_1 's is not necessary if the counting intervals are of constant length, and only the slope of the decay curve is desired. The precise method should be used if one wishes to extrapolate the decay curve back to zero time.

During the actual conduction of the experiment it was observed that following the turning on of the count switch on the scaler, a brief period of time elapsed before any counts were registered. Thus the scaler seemed to have an inherent delay time between the time the count switch was turned on and counts were actually recorded. On the basis of this observation it was necessary to discard the data obtained for the first time interval since actually the scaler was not functioning properly for the full 3 time units. Thus only four points were used to determine the half-life of the radioisotope.

Table 1 is a summary of the Al^{25} data needed to compute the half-life. The y_1 were determined from the data in Appendix I, and σ was computed by utilizing formula (11).

x_i (time units)	y_i (net counts)	σ_i	y'_i	w'_i ($\times 10^2$)	$y'_i w'_i$ ($\times 10^2$)
6	3,192	$\pm .66$	3.30406	28.523	195.136
11	1,929	$\pm .56$	3.28533	7.170	78.950
16	1,070	$\pm .47$	3.28238	1.225	19.600
21	690	$\pm .43$	2.93835	.321	6.968
				61.254	300.554

x_i (time units)	y_i (net counts)	$x_i^2 w'_i$ ($\times 10^2$)	$x_i y'_i w'_i$ ($\times 10^2$)	$y'_i w'_i$ ($\times 10^2$)
6	3,192	1,170.828	683.775	113.962
11	1,929	844.538	259.403	23.582
16	1,070	313.600	59.376	3.711
21	690	14.648	19.254	.921
		2,487.614	1,022.102	142.166

Table 1. Summary of Data for Al^{25} .

Using Table 1 and equations (17) one may easily compute n' and k' . The quantity n' is computed to be $-.04515$ (time units) $^{-1}$, while k' comes out to be 3.77559. Now since $n' = n \log_{10} e = .434$,

$$n = -.04515 / .434 = -.1040 = .093 / \text{H.L.} \quad (23).$$

From equation (23) the half-life of Al^{25} , H.L., is readily found to be 6.67 time units or 7.11 sec.

It has been shown⁽³²⁾ that an estimate of the standard

Group	Species	Length	Sex	Age	Spots
100-120	Stellifer	100-120	♂	juv	0
120-140	Stellifer	120-140	♂	juv	22
140-160	Stellifer	140-160	♂	juv	44
160-180	Stellifer	160-180	♂	juv	66
180-200	Stellifer	180-200	♂	juv	88
200-220	Stellifer	200-220	♂	juv	110
220-240	Stellifer	220-240	♂	juv	132
240-260	Stellifer	240-260	♂	juv	154
260-280	Stellifer	260-280	♂	juv	176
280-300	Stellifer	280-300	♂	juv	198
300-320	Stellifer	300-320	♂	juv	220
320-340	Stellifer	320-340	♂	juv	242
340-360	Stellifer	340-360	♂	juv	264
360-380	Stellifer	360-380	♂	juv	286
380-400	Stellifer	380-400	♂	juv	308
400-420	Stellifer	400-420	♂	juv	330
420-440	Stellifer	420-440	♂	juv	352
440-460	Stellifer	440-460	♂	juv	374
460-480	Stellifer	460-480	♂	juv	396
480-500	Stellifer	480-500	♂	juv	418
500-520	Stellifer	500-520	♂	juv	440
520-540	Stellifer	520-540	♂	juv	462
540-560	Stellifer	540-560	♂	juv	484
560-580	Stellifer	560-580	♂	juv	506
580-600	Stellifer	580-600	♂	juv	528
600-620	Stellifer	600-620	♂	juv	550
620-640	Stellifer	620-640	♂	juv	572
640-660	Stellifer	640-660	♂	juv	594
660-680	Stellifer	660-680	♂	juv	616
680-700	Stellifer	680-700	♂	juv	638
700-720	Stellifer	700-720	♂	juv	660
720-740	Stellifer	720-740	♂	juv	682
740-760	Stellifer	740-760	♂	juv	704
760-780	Stellifer	760-780	♂	juv	726
780-800	Stellifer	780-800	♂	juv	748
800-820	Stellifer	800-820	♂	juv	770
820-840	Stellifer	820-840	♂	juv	792
840-860	Stellifer	840-860	♂	juv	814
860-880	Stellifer	860-880	♂	juv	836
880-900	Stellifer	880-900	♂	juv	858
900-920	Stellifer	900-920	♂	juv	880
920-940	Stellifer	920-940	♂	juv	902
940-960	Stellifer	940-960	♂	juv	924
960-980	Stellifer	960-980	♂	juv	946
980-1000	Stellifer	980-1000	♂	juv	968
1000-1020	Stellifer	1000-1020	♂	juv	990
1020-1040	Stellifer	1020-1040	♂	juv	1012
1040-1060	Stellifer	1040-1060	♂	juv	1034
1060-1080	Stellifer	1060-1080	♂	juv	1056
1080-1100	Stellifer	1080-1100	♂	juv	1078
1100-1120	Stellifer	1100-1120	♂	juv	1090
1120-1140	Stellifer	1120-1140	♂	juv	1112
1140-1160	Stellifer	1140-1160	♂	juv	1134
1160-1180	Stellifer	1160-1180	♂	juv	1156
1180-1200	Stellifer	1180-1200	♂	juv	1178
1200-1220	Stellifer	1200-1220	♂	juv	1190
1220-1240	Stellifer	1220-1240	♂	juv	1212
1240-1260	Stellifer	1240-1260	♂	juv	1234
1260-1280	Stellifer	1260-1280	♂	juv	1256
1280-1300	Stellifer	1280-1300	♂	juv	1278
1300-1320	Stellifer	1300-1320	♂	juv	1290
1320-1340	Stellifer	1320-1340	♂	juv	1312
1340-1360	Stellifer	1340-1360	♂	juv	1334
1360-1380	Stellifer	1360-1380	♂	juv	1356
1380-1400	Stellifer	1380-1400	♂	juv	1378
1400-1420	Stellifer	1400-1420	♂	juv	1390
1420-1440	Stellifer	1420-1440	♂	juv	1412
1440-1460	Stellifer	1440-1460	♂	juv	1434
1460-1480	Stellifer	1460-1480	♂	juv	1456
1480-1500	Stellifer	1480-1500	♂	juv	1478
1500-1520	Stellifer	1500-1520	♂	juv	1490
1520-1540	Stellifer	1520-1540	♂	juv	1512
1540-1560	Stellifer	1540-1560	♂	juv	1534
1560-1580	Stellifer	1560-1580	♂	juv	1556
1580-1600	Stellifer	1580-1600	♂	juv	1578
1600-1620	Stellifer	1600-1620	♂	juv	1590
1620-1640	Stellifer	1620-1640	♂	juv	1612
1640-1660	Stellifer	1640-1660	♂	juv	1634
1660-1680	Stellifer	1660-1680	♂	juv	1656
1680-1700	Stellifer	1680-1700	♂	juv	1678
1700-1720	Stellifer	1700-1720	♂	juv	1690
1720-1740	Stellifer	1720-1740	♂	juv	1712
1740-1760	Stellifer	1740-1760	♂	juv	1734
1760-1780	Stellifer	1760-1780	♂	juv	1756
1780-1800	Stellifer	1780-1800	♂	juv	1778
1800-1820	Stellifer	1800-1820	♂	juv	1790
1820-1840	Stellifer	1820-1840	♂	juv	1812
1840-1860	Stellifer	1840-1860	♂	juv	1834
1860-1880	Stellifer	1860-1880	♂	juv	1856
1880-1900	Stellifer	1880-1900	♂	juv	1878
1900-1920	Stellifer	1900-1920	♂	juv	1890
1920-1940	Stellifer	1920-1940	♂	juv	1912
1940-1960	Stellifer	1940-1960	♂	juv	1934
1960-1980	Stellifer	1960-1980	♂	juv	1956
1980-2000	Stellifer	1980-2000	♂	juv	1978
2000-2020	Stellifer	2000-2020	♂	juv	1990
2020-2040	Stellifer	2020-2040	♂	juv	2012
2040-2060	Stellifer	2040-2060	♂	juv	2034
2060-2080	Stellifer	2060-2080	♂	juv	2056
2080-2100	Stellifer	2080-2100	♂	juv	2078
2100-2120	Stellifer	2100-2120	♂	juv	2090
2120-2140	Stellifer	2120-2140	♂	juv	2112
2140-2160	Stellifer	2140-2160	♂	juv	2134
2160-2180	Stellifer	2160-2180	♂	juv	2156
2180-2200	Stellifer	2180-2200	♂	juv	2178
2200-2220	Stellifer	2200-2220	♂	juv	2190
2220-2240	Stellifer	2220-2240	♂	juv	2212
2240-2260	Stellifer	2240-2260	♂	juv	2234
2260-2280	Stellifer	2260-2280	♂	juv	2256
2280-2300	Stellifer	2280-2300	♂	juv	2278
2300-2320	Stellifer	2300-2320	♂	juv	2290
2320-2340	Stellifer	2320-2340	♂	juv	2312
2340-2360	Stellifer	2340-2360	♂	juv	2334
2360-2380	Stellifer	2360-2380	♂	juv	2356
2380-2400	Stellifer	2380-2400	♂	juv	2378
2400-2420	Stellifer	2400-2420	♂	juv	2390
2420-2440	Stellifer	2420-2440	♂	juv	2412
2440-2460	Stellifer	2440-2460	♂	juv	2434
2460-2480	Stellifer	2460-2480	♂	juv	2456
2480-2500	Stellifer	2480-2500	♂	juv	2478
2500-2520	Stellifer	2500-2520	♂	juv	2490
2520-2540	Stellifer	2520-2540	♂	juv	2512
2540-2560	Stellifer	2540-2560	♂	juv	2534
2560-2580	Stellifer	2560-2580	♂	juv	2556
2580-2600	Stellifer	2580-2600	♂	juv	2578
2600-2620	Stellifer	2600-2620	♂	juv	2590
2620-2640	Stellifer	2620-2640	♂	juv	2612
2640-2660	Stellifer	2640-2660	♂	juv	2634
2660-2680	Stellifer	2660-2680	♂	juv	2656
2680-2700	Stellifer	2680-2700	♂	juv	2678
2700-2720	Stellifer	2700-2720	♂	juv	2690
2720-2740	Stellifer	2720-2740	♂	juv	2712
2740-2760	Stellifer	2740-2760	♂	juv	2734
2760-2780	Stellifer	2760-2780	♂	juv	2756
2780-2800	Stellifer	2780-2800	♂	juv	2778
2800-2820	Stellifer	2800-2820	♂	juv	2790
2820-2840	Stellifer	2820-2840	♂	juv	2812
2840-2860	Stellifer	2840-2860	♂	juv	2834
2860-2880	Stellifer	2860-2880	♂	juv	2856
2880-2900	Stellifer	2880-2900	♂	juv	2878
2900-2920	Stellifer	2900-2920	♂	juv	2890
2920-2940	Stellifer	2920-2940	♂	juv	2912
2940-2960	Stellifer	2940-2960	♂	juv	2934
2960-2980	Stellifer	2960-2980	♂	juv	2956
2980-3000	Stellifer	2980-3000	♂	juv	2978
3000-3020	Stellifer	3000-3020	♂	juv	2990
3020-3040	Stellifer	3020-3040	♂	juv	3012
3040-3060	Stellifer	3040-3060	♂	juv	3034
3060-3080	Stellifer	3060-3080	♂	juv	3056
3080-3100	Stellifer	3080-3100	♂	juv	3078
3100-3120	Stellifer	3100-3120	♂	juv	3090
3120-3140	Stellifer	3120-3140	♂	juv	3112
3140-3160	Stellifer	3140-3160	♂	juv	3134
3160-3180	Stellifer	3160-3180	♂	juv	3156
3180-3200	Stellifer	3180-3200	♂	juv	3178
3200-3220	Stellifer	3200-3220	♂	juv	3190
3220-3240	Stellifer	3220-3240	♂	juv	3212
3240-3260	Stellifer	3240-3260	♂	juv	3234
3260-3280	Stellifer	3260-3280	♂	juv	3256
3280-3300	Stellifer	3280-3300	♂	juv	3278
3300-3320	Stellifer	3300-3320	♂	juv	3290
3320-3340	Stellifer	3320-3340	♂	juv	3312
3340-3360	Stellifer	3340-3360	♂	juv	3334
3360-3380	Stellifer	3360-3380	♂	juv	3356
3380-3400	Stellifer	3380-3400	♂	juv	3378
3400-3420	Stellifer	3400-3420	♂	juv	3390
3420-3440	Stellifer	3420-3440	♂	juv	3412
3440-3460	Stellifer	3440-3460	♂	juv	3434
3460-3480	Stellifer	3460-3480	♂	juv	3456
3480-3500	Stellifer	3480-3500	♂	juv	3478
3500-3520	Stellifer	3500-3520	♂	juv	3490
3520-3540	Stellifer	3520-3540	♂	juv	3512
3540-3560	Stellifer	3540-3560	♂	juv	3534
3560-3580	Stellifer	3560-3580	♂	juv	3556
3580-3600	Stellifer	3580-3600	♂	juv	3578
3600-3620	Stellifer	3600-3620	♂	juv	3590
3620-3640	Stellifer	3620-3640	♂	juv	3612
3640-3660	Stellifer	3640-3660	♂	juv	3634
3660-3680	Stellifer	3660-3680	♂	juv	3656
3680-3700	Stellifer	3680-3700	♂	juv	3678
3700-3720	Stellifer	3700-3720	♂	juv	3690
3720-3740	Stellifer	3720-3740	♂	juv	3712
3740-3760	Stellifer	3740-3760	♂	juv	3734
3760-3780	Stellifer	3760-3780	♂	juv	3756
3780-3800	Stellifer	3780-3800	♂	juv	3778
3800-3820	Stellifer	3800-3820	♂	juv	3790
3820-3840</					

error of n' may be obtained from

$$(S.E. \text{ in } n')^2 = C_{22} \sigma^2_{(\text{ext})} \quad (24)$$

where

$$C_{22} = \sum w_i^2 / D' \quad (25)$$

in which D' is the D defined by equation (18) with w_i^2 substituted for w_i and y_i^2 for y_i ;

and

$$\sigma^2_{(\text{ext})} = \sum w_i^2 d_i^2 / (n-p) \quad (26)$$

in which n is the number of points to be fitted, and p is the number of adjustable parameters. In this case $n-p$ is 2. Application of equation (24) leads to S.E. in $n' = \pm .00300$ and ultimately the S.E. in the half-life of $\text{Al}^{25} = \pm .20$ sec. Thus the half-life of Al^{25} is reported as $7.11 \pm .13$ sec., where $.13 = (.67)(\text{S.E.}) = \text{probable error}$. Figure 6 is a graph of the decay of Al^{25} .

The data listed in Appendix II is summarized in Table 2. Computations precisely similar to those made for Al^{25} were performed for Al^{26} , indicating the half-life of Al^{26} to be $7.61 \pm .21$ sec., where the $\pm .21$ sec. is probable error. Figure 7 is a graph of the decay of Al^{26} .

The values obtained by these experiments for the half-lives of Al^{25} and Al^{26} should now be compared with values reported by other research workers using different methods. Bradner and Gow⁽¹⁹⁾ have reported the half-life of Al^{25} to be 7.3 sec. They bombarded Mg^{25} with protons from a linear accelerator and found an activity of 7.3 sec. which they

1928-1930

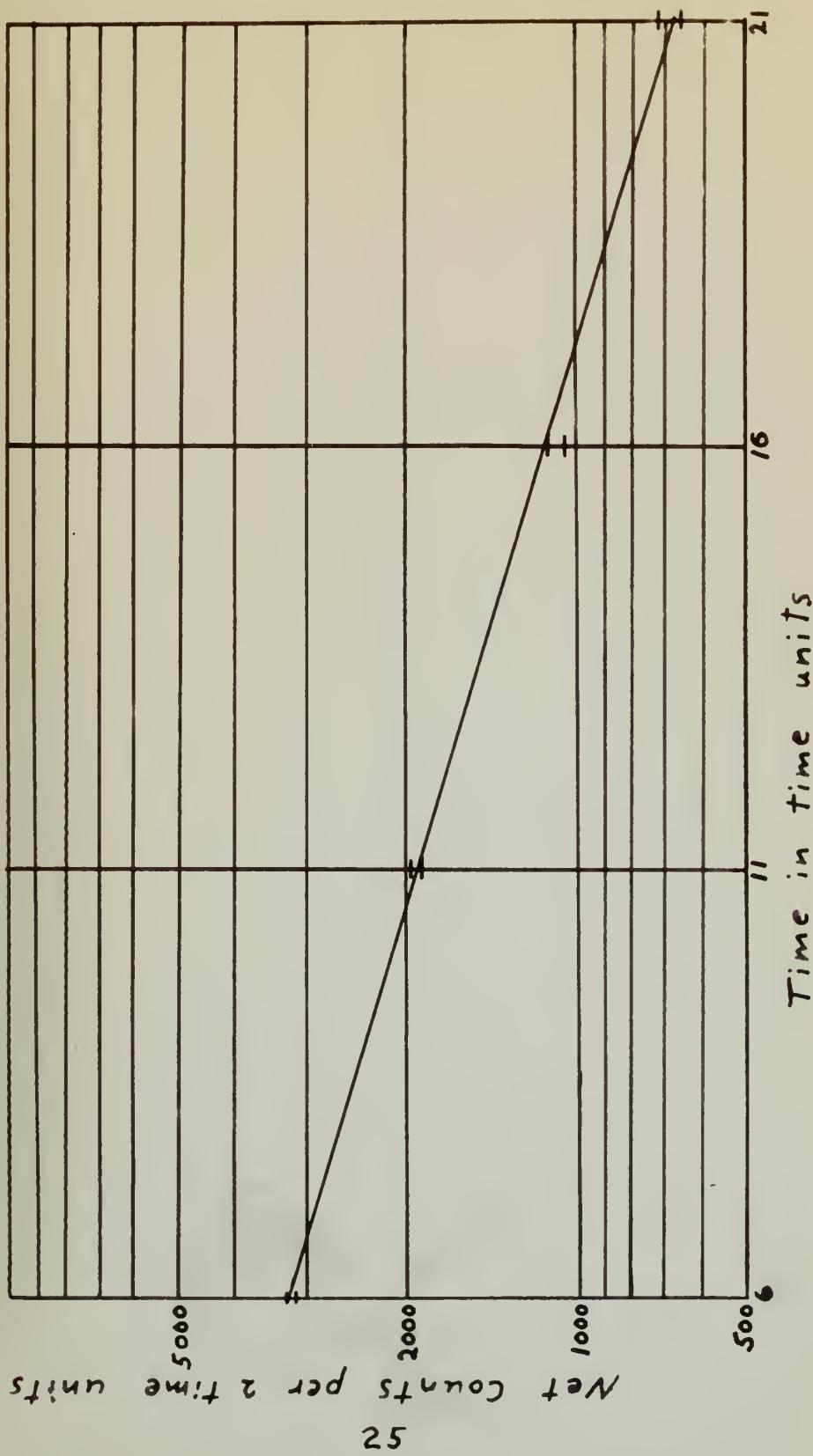
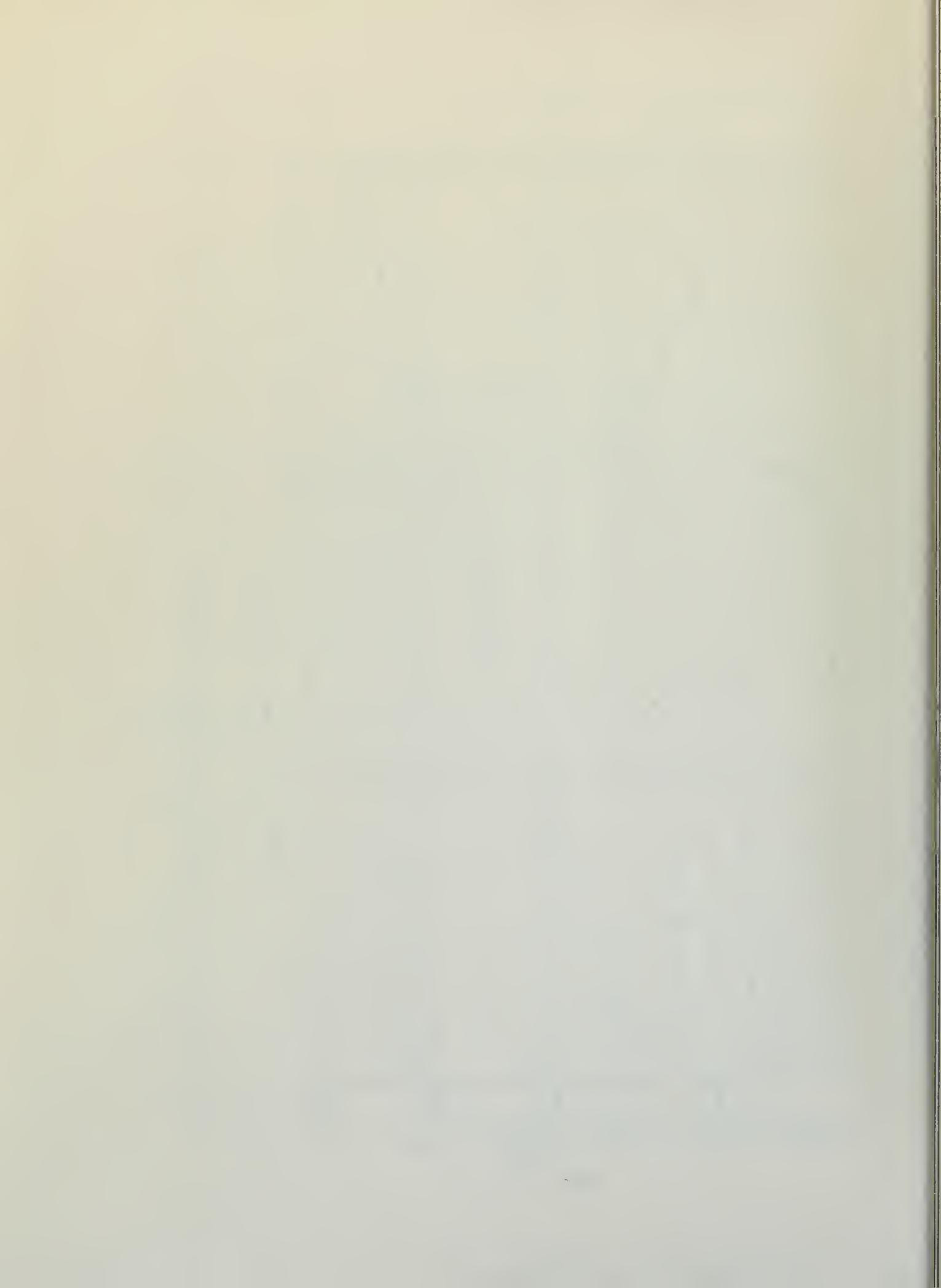


Figure 6. Decay curve of Al^{25} .



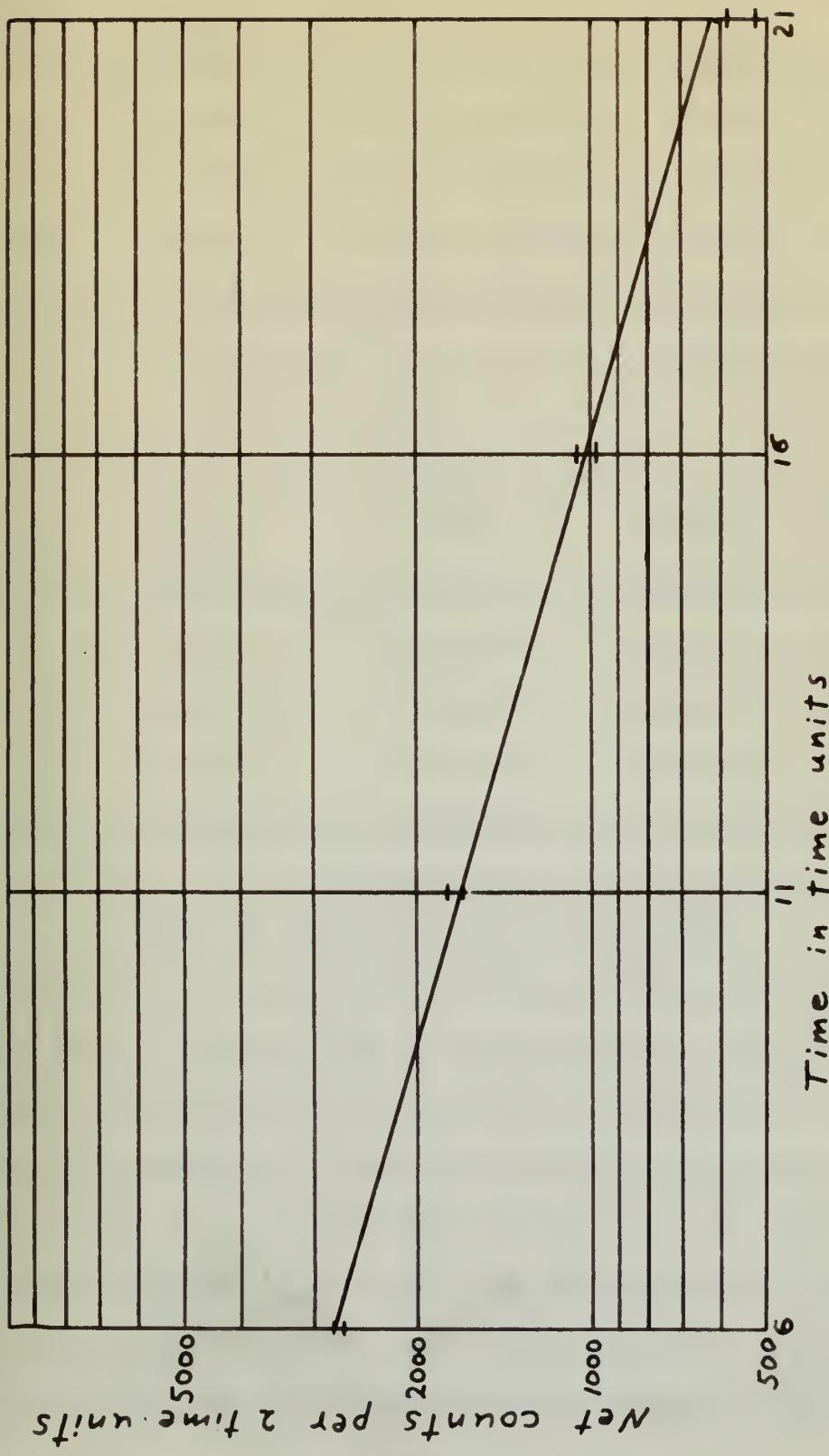


Figure 7. Decay curve of Al^{26} .



x_i (time units)	y_i (net counts)	σ_i	\bar{x}_i	\bar{y}_i ($\times 10^2$)	\bar{z}_i ($\times 10^2$)
6	1,713	± 35	3.1335	19.959	119.124
11	1,713	± 49	3.21375	5.026	51.206
16	1,034	± 41	3.00345	1.024	14.334
21	250	± 35	2.71025	.120	1.116
				2.135	11.270

x_i (time units)	y_i (net counts)	$x_i^2 y_i^2$ ($\times 10^2$)	$x_i y_i v_i$ ($\times 10^2$)	y_i^2 ($\times 10^2$)
6	1,713	718.374	411.375	68.562
11	1,713	603.116	171.702	16.233
16	1,034	367.144	49.222	3.076
21	250	71.206	9.252	.452
		1,662.370	646.912	10.316

Table 2. Summary of Data for Al^{25} .

attributed to the reaction $Fe^{25}(p, n) Al^{25}$. It is thus seen that the results of this experiment agree quite closely with those of Bradner and Gow for Al^{25} . Bradner and Gow did not give the details of their experimental arrangement, nor the energy of the bombarding protons, nor probable error in their result. There are very few reports in the literature listing a half-life for Al^{25} . This is undoubtedly due to the fact that only recently have separated isotopes of

ing been available. The common procedure in the past has been to bombard a target of unseparated aluminum with protons. This gives a mixture of the two isotopes Al^{25} and Al^{26} , and since their half-lives are so close together, the decay curve obtained cannot in general be resolved into two components.

Quite in contrast to the case for Al^{25} there are many values reported in the literature for the half-life of Al^{26} . The latest value is 6.3 sec. and was reported by Bradner and Gow in the same article in which they reported on Al^{25} . The reaction they used in this case was $\text{Al}^{26}(\text{p},\text{n}) \text{Al}^{26}$ where again the protons were supplied by a linear accelerator. Other older values⁽²⁰⁾⁻⁽²⁶⁾ in the literature for the half-life of Al^{26} , however, range from 7.0 sec. to 8.5 sec., with most of the values centering around 7.0 sec. Bradner and Gow have suggested that the 7.0 sec. half-life normally given for Al^{26} is probably a mixture of Al^{25} and Al^{26} . This may be true in some cases but it is difficult to see how it could possibly be true in others. For example, Perlman and Friedlander⁽²⁰⁾ used the reaction $\text{Al}^{27}(\text{r},\text{n}) \text{Al}^{26}$ which certainly should have given them almost pure Al^{26} . Any Al^{25} which they would have gotten would have come from the reaction $\text{Al}^{27}(\text{r},2\text{n}) \text{Al}^{25}$ which has a very small cross section compared to the (r,n) reaction. The half-life reported by them for Al^{26} was

7.0 sec.affler and Mirzel⁽²¹⁾ have also used the $\text{Al}^{27}(\gamma, n)$ Al^{26} reaction; they report the half-life of Al^{26} to be 7.2 sec. In a pioneer experiment in this field Frieh⁽²³⁾, employing the reaction $\text{Ta}^{23}(\alpha, n)$ Al^{26} , obtained a value of 7 ± 1 sec. for the half-life of Al^{26} . Huber et al⁽²⁶⁾, employing the reaction $\text{Al}^{27}(\gamma, n)$ Al^{26} , obtained a half-life of $7.2 \pm .5$ sec. for Al^{26} . In all cases reported^{(22), (24), (25)} where one would reasonably expect the true activity measured to be a mixture of Al^{25} and Al^{26} only a simple decay curve has been observed. This would tend to indicate that the true half-lives of Al^{25} and Al^{26} are quite close together.

The value found in this experiment for the half-life of Al^{26} , $7.61 \pm .21$ sec., does not agree with the 6.3 sec. of Bradner and Gow. No explanation is offered for this discrepancy other than the fact that the value found in this work does agree with that reported by researchers⁽²⁶⁾ other than Bradner and Gow. No possible explanation is that there are two isomeric states of Al^{26} with quite close half-lives.

Discussion of New Method's Capabilities and Limitations

It is manifestly to be regretted that there was no opportunity to conduct an experiment which would have utilized the new method in its originally described manner.

The main reason for deciding to use the half-lives of Al^{25} and Al^{26} instead of any other radioactive pairs was the fact that this knowledge was desired in collaboration with work at this university of J. B. Taylor and A. H. Russell on measuring nuclear resonance peaks for the reactions $\text{Ag}^{24}(\text{p},\gamma)\text{Al}^{25}$ and $\text{Ag}^{25}(\text{p},\gamma)\text{Al}^{26}$. The author feels certain that if time would have permitted the performance of another experiment, the apparatus described would have worked satisfactorily in its originally described way.

The main advantages of this new method are its simplicity of design, the fact that it utilizes mostly commercially available equipment, and its great flexibility of application over a wide range of half-lives, 1 millisecond to 1 min. For all half-lives longer than 1 sec. the adaptation used in the Al^{25} and Al^{26} experiments is probably more practical than the first-described method.

One of the limitations which should be mentioned includes the large number of runs which would be necessary to insure a small probable error using the first method. Since the half-life would be computed on the basis of only three points, those points would have to be chosen. Also if the method were to be used to measure half-lives shorter than approximately 10^{-3} sec., the Geiger tube should be replaced by a scintillation counter. This would be necessary

since longer tubes have dead times on the order of 10^{-7} sec. and too many coincidence counts would be lost. Actually since scintillation counter dead times are of the order of 10^{-6} sec., this method is capable of measuring half-lives on the order of 10^{-7} sec. if an auxiliary fast oscilloscope sweep were constructed, and if an electronic shutter of some type were utilized.

Another minor limitation is the fact that in the modification employed in the current experiments the number of counts obtained at a given voltage setting on the 931-A phototube is very sensitive to the gain control on the amplifier used. This made it necessary to calibrate the phototube part of the apparatus by feeding a known frequency pulse from a pulse generator into the vertical deflection plates of the oscilloscope and adjusting the gain control on the amplifier until the scaler connected to the output of the phototube recorded the correct number of counts. The variable controls were not touched again then during an entire experiment. In reality this is not a serious defect since all that is actually required is that the gain remain constant over the few seconds of each individual run.

There are several radionuclides whose half-lives might profitably be checked by this new method. Some of these are listed below, together with the reported values of the half-lives. (27), (30), (31)

Isotope	Half-life (sec.)	Reaction	(Eov.)
B^{12}	2.7, 2.2×10^{-2}	$\text{B}^{11}(\text{d}, \text{p})\text{B}^{12}$	0.4
He^6	.35, .37, .8	$\text{Be}^9(\alpha, \text{n})\text{He}^6$	-0.8
Li^6	.3, .39	$\text{Li}^7(\text{d}, \text{p})\text{Li}^6$	-0.20
Al^{35}	2.2, 1.14, 1.88	$\text{Cl}^{35}(\text{p}, \text{n})\text{Al}^{35}$	-5.6
Cl^{33}	2.6, 2.4	$\text{Cl}^{32}(\text{d}, \text{n})\text{Cl}^{33}$.55
P^{31}	2.9, 3.2	$\text{P}^{31}(\text{p}, \text{n})\text{S}^{31}$	-5.0
Si^{27}	4.9, 4.5	$\text{Al}^{27}(\text{p}, \text{n})\text{Si}^{27}$	-3.4
P^{16}	7.3, 8	$\text{N}^{15}(\text{d}, \text{p})\text{P}^{16}$	0.5
I^{23}	11.6, 11.9, 12	$\text{La}^{23}(\text{p}, \text{n})\text{I}^{23}$	-4.5
Cl^{12}	12.5×10^{-3}	$\text{Cl}^{12}(\text{p}, \text{n})\text{K}^{12}$	-10.5
Sc^{41}	.37	$\text{Ca}^{40}(\text{d}, \text{n})\text{Sc}^{41}$.33*
Ca^{39}	1.06	$\text{Ca}^{40}(\text{r}, \text{n})\text{Ca}^{39}$	-14.5
P^{29}	4.6	$\text{Si}^{28}(\text{d}, \text{n})\text{P}^{29}$	-0.80
K^{37}	1.3	$\text{K}^{39}(\text{r}, 2\text{n})\text{K}^{37}$	-24
Ti^{43}	.56	$\text{Ca}^{40}(\alpha, \text{n})\text{Ti}^{43}$	-0.6
Cu^{58}	3	$\text{Ni}^{58}(\text{p}, \text{n})\text{Cu}^{58}$	-10.5
Tr^{97}	1-2	Fission	--
Nb^{90-94}	short	Fission	--
Ca^{41}	?	$\text{Ca}^{40}(\text{d}, \text{p})\text{Ca}^{41}$	6.09

Of course, there are many other short-lived radioisotopes in addition to the ones listed.

*These values were computed using mass values as given by I. Petrakalis and G. Leitwissler, "Table of Atomic Masses", Argonne National Laboratory, 1950.

Another very interesting experiment which could be done would be to measure the half-life of Al^{26} from the reaction $\text{Mg}^{25}(\text{p},\gamma) \text{Al}^{26}$ for different energies of the bombarding protons. Different values of half-lives at different energies would indicate the existence of isomeric states of Al^{26} . Curran and Strothers⁽²⁵⁾ performed this experiment with an unseparated Mg target in 1939, and their results suggest the possibility that indeed different half-lives might be found at different bombarding proton energies.

Summary

A new method of measuring short half-lives in the range from 1 millisecond. to 1 min. has been described. This method has then been applied to the problems of determining the half-lives of Al^{25} and Al^{26} with the following results: Al^{25} -7.11 \pm .13 sec.; Al^{26} -7.61 \pm .21 sec. Some capabilities and limitations of the method have been discussed and future applications have been suggested.

and human-made structures are covered with greenish
algae until 2000 m elevation the ground is covered with
soil due to intense erosion and ^{238}U (^{232}Th and ^{231}Pa) and ^{226}Ra
which are probably the major sources. Human induced
process like mining and mining areas between 2000
metres above elevation ^{238}U concentration has been ^{238}U to
over 1000 ppm up to areas of concentration of 1000 ppm
which corresponds to the same concentration of ^{226}Ra
and ^{228}Th which are found in the same area.

There are two kinds of greenish algae in the soil with a
soft, velvety coat and with 2-3 cm thickness. A soft green
algae can grow on soil and rock and has
thickness about 1-2 mm ^{238}U to ^{226}Ra and
 ^{228}Th concentration are 200-300 ppm (L. Z. Zay-Pai
has been found that these algae can be used to live
algae and used as fertilizer and

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Appendix I

Data for ^{162}Ge (p, γ) ^{41}Ca experiment.

Background: 1034 counts in 467 sec.

All time intervals 2 time units or $2(6/60)$ sec. long.

The numbers recorded are 2 times the actual accumulated counts.

1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th
92	162	138	226	246	46	74	96	104	112
72	65	120	132	132	40	56	102	102	116
112	194	252	302	320	12	22	34	32	32
94	122	176	210	280	152	256	304	342	358
74	110	140	174	190	126	196	230	244	270
94	148	216	226	242	146	174	196	240	260
54	84	138	158	170	12	22	22	32	44
64	108	152	152	178	30	38	2	46	64
36	50	145	145	243	62	116	134	132	134
13	21	286	296	358	46	60	140	148	150
1	172	208	260	276	108	112	165	212	220
176	292	334	356	366	78	124	150	160	160
96	150	218	274	314	38	62	94	154	166
7	136	154	174	190	72	80	144	172	208
14	92	112	110	136	134	17	216	260	264
90	182	230	266	256	120	232	272	312	350
156	2	36	450	470	124	156	194	230	212
134	172	196	222	256	58	76	1	1	1
172	206	274	416	60	102	132	132	140	140
60	204	240	30	310	54	146	104	210	230
10	22	22	38	46	30	74	112	122	128
92	116	134	154	196	62	96	110	117	128
66	110	124	140	174	116	212	274	310	320
55	122	152	206	236	76	116	156	166	172
11	20	260	290	314	11	146	13	12	212
35	36	110	12	154	76	136	161	18	206
124	84	242	254	275	56	114	161	192	216
11	66	7	152	11	112	112	140	130	140
116	21	252	292	320	114	116	122	122	174
232	39	540	524	540	116	212	104	160	270
100	220	316	426	42	56	370	152	512	532
55	76	110	110	120	76	122	148	170	198
11	74	76	50	36	92	110	192	208	236

the same time, the number of the *littera* is also increased.

Consequently the *littera* of the *littera* can be

seen both as a *littera* and as a *littera* of a *littera*. The *littera* of a *littera* is a *littera* of a *littera* of a *littera* and so on. This is a very interesting and important discovery.

It is also interesting to note that the *littera* of a *littera* is a *littera* of a *littera* of a *littera* and so on.

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	1st	2nd	3rd	4th	5th
Mean	11,302	1,072	23,910	27,700	29,790
\pm S.D.	2,354	9,436	11,225	13,615	11,223
Differences	5,654	3,762	2,719	1,660	1,230
- S.D.	5,064	3,192	1,929	1,070	990

1900-1901

Time for $n=15$ (μ, γ) $\approx 10^6$ μ sec.

and 2nd: 750 entries in 1,200 v. c.

All the intervals 2 times wider than ± 0.05 (5%) size, 100.

The values recorded are 2 times the actual current of each.

67 71 76 83 90 97 102 109 116 123 130 137 144 151 158 165 172 179 186 193 199 206 213 220 227 234 241 248 255 262 269 276 283 290 297 304 311 318 325 332 339 346 353 360 367 374 381 388 395 398 405 412 419 426 433 440 447 454 461 468 475 482 489 496 499 506 513 520 527 534 541 548 555 562 569 576 583 590 597 604 611 618 625 632 639 646 653 660 667 674 681 688 695 698 705 712 719 726 733 740 747 754 761 768 775 782 789 796 799 806 813 820 827 834 841 848 855 862 869 876 883 890 897 904 911 918 925 932 939 946 953 960 967 974 981 988 995 1002 1009 1016 1023 1030 1037 1044 1051 1058 1065 1072 1079 1086 1093 1096 1103 1110 1117 1124 1131 1138 1145 1152 1159 1166 1173 1180 1187 1194 1201 1208 1215 1222 1229 1236 1243 1250 1257 1264 1271 1278 1285 1292 1299 1306 1313 1320 1327 1334 1341 1348 1355 1362 1369 1376 1383 1390 1397 1404 1411 1418 1425 1432 1439 1446 1453 1460 1467 1474 1481 1488 1495 1502 1509 1516 1523 1530 1537 1544 1551 1558 1565 1572 1579 1586 1593 1596 1603 1610 1617 1624 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the first time in the history of the world, the people of the United States have been called upon to decide whether they will submit to the law of force, and to become a nation of cowards and slaves.

It is a law that has been in force for ages, and it is natural for the people to submit to it. It is a law that has been in force for ages, and it is natural for the people to submit to it.

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